

Track Segments within Hadronic Showers using the CALICE AHCAL

Lars Weuste^{1,2}

1- Max-Planck-Institut für Physik, Munich, Germany

2- Excellence Cluster 'Universe', TU München, Garching, Germany

Using the high granular CALICE analog hadron calorimeter (AHCAL) a tracking algorithm capable of identifying MIP-like tracks within hadronic showers is presented. Such an algorithm provides excellent tools for detector calibration and for studies of the substructure of hadronic showers. The properties of the identified tracks are used as observables for a Monte-Carlo to data comparison.

1 The CALICE analog hadron calorimeter

The CALICE (*Cal*orimeter for a *L*inear *C*ollider *E*xperiment) collaboration performed tests of new calorimeter technologies for the planned International Linear Collider (ILC). Several prototypes were investigated during the testbeam phase at DESY (2006), CERN (2006 & 2007) and FNAL (2008 & 2009).

The analog hadron calorimeter (AHCAL, [1]) has been successfully used in all five testbeams. It is a sampling calorimeter with a size of $\approx 1 \text{ m}^3$ with 38 layers using 2 cm of steel as absorbing material, resulting in a depth of approximately $5.3 \lambda_I$ ($\approx 4.5 \lambda_I$ for pions). The active layers have a very granular structure, using scintillator tiles from $3 \times 3 \text{ cm}^2$ up to $12 \times 12 \text{ cm}^2$. Each scintillator tile is read out with a Silicon Photomultiplier.

This granular structure allows for identification of tracks generated by Minimum Ionizing Particles (MIP) passing through (parts of) the detector. This capability is an excellent tool for detector calibration[2] and provides the possibility for detailed studies of the shower substructure. This article presents an algorithm for the identification of MIP-like track segments within hadronic showers (see Section 2).

A few examples of identified MIP tracks are displayed in Figure 1. As one can see, the tracks provide information on the 3D substructure of hadronic showers. This information is used for confronting Monte Carlo simulations with data (Section 3).

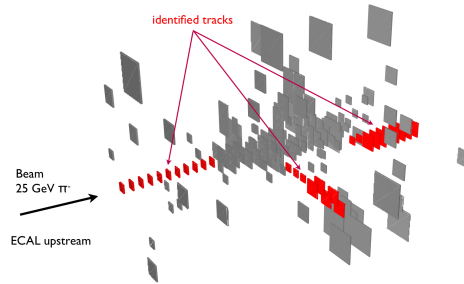


Figure 1: Typical hadronic shower response/development in CALICE AHCAL for a 25 GeV π^- run.

2 The tracking algorithm

To provide a clean sample of tracks by minimum ionizing particles in the environment of a hadronic shower, which includes regions of high local particle density, specific selections criteria for the calorimeter cells used by the tracking algorithm are necessary. A sample of

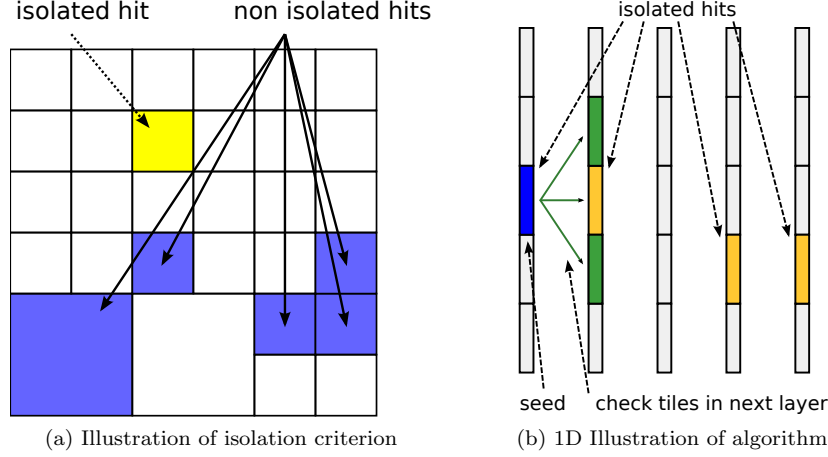


Figure 2: Illustration of isolation criterion and algorithm.

the detector cells very likely being traversed only by a single particle is selected by imposing an isolation criterion, illustrated in Figure 2a. A hit is called isolated if there is no direct neighbour cell with a hit within the same layer. The tracking algorithm will only use hits fulfilling this criterion.

As there is no magnetic field in the CALICE experiment, the presented algorithm was optimized for finding straight tracks.

2.1 Track Finding

The tracking algorithm used for identification of single particle tracks is a local search method working layer by layer. A track is followed from the beginning to the end.

The algorithm has the following steps:

1. Search for isolated hits in all layers using the introduced isolation criterion. A cell is called hit if the energy deposited exceeds 0.4 MIP. A MIP is defined as the most probable energy deposition of a single passing minimum ionizing particle.
2. Use the isolated hits as start point (seed), starting from the first layer in beam direction. For each of these points:
 - (a) Increment by one layer in beam direction and search for unused isolated hits that can continue the current track. The search window is ± 1 cells in x and y (when z is beam axis), resulting in 9 checked cells. For a 1D illustration see Figure 2b.
 - (b) Repeat last step until the end of the detector is reached or no continuation hit can be found. The algorithm allows for gaps, i.e. maximum one consecutive layer with no hit.
3. Once the track is completed, start over with the remaining isolated hits in the detector to find more tracks.

As the algorithm works layer-wise for each track there is a maximum of one hit per layer. With the isolation criterion it is then very likely that the found track was generated by a single particle.

3 Monte-Carlo to Data comparison

The characteristics of MIP-like tracks reflects the spatial structure of hadronic showers. By comparing to simulation the shower modeling provided by the different physics lists can be validated. Here, the two following parameters were chosen: track angle and track length.

The comparison was done using these physics lists from Mokka/Geant4[3]:
 QGSP_BERT, QGSP_BERT_TRV, QGS_BIC, LHEP, FTF_BIC, FTFP_BERT

The comparison of the actual distribution is done for π^- data at an energy of 25 GeV. For energies in the range from 10 GeV up to 80 GeV the mean value was used for comparison.

3.1 Track angle

The track angle is sensitive to the scattering angle of secondary particles created in hadronic showers and hence the shower structure.

The comparison for the angle distribution of the tracks is shown in Figure 3a for 25 GeV. The distribution shows many tracks at angles θ lower than 5° ($\approx 20\%$ of all tracks). As in every event the incident particle is not inclined, the initial track of the incoming particle is major contributor to those at low angles. If we go to higher angles, the number of tracks found decreases until it vanishes for $\theta > 65^\circ$. This is not necessarily due to the shower shape but the incapability of the used algorithm to identify tracks at very large angles.

All physics lists considered with the exception of LHEP and QGS_BIC provide an angular distribution of tracks that is similar to the one observed in data. The tracks produced by LHEP and QGS_BIC have too low average angles.

This can be seen as well when comparing the mean value for the complete energy range shown in Figure 3b. LHEP is significantly below the data over the whole energy range, while QGS_BIC performs better but is still too low. The remaining physics lists are again quite close together and reproduce the result from data better, while they all tend to produce tracks at lower angles than testbeam data, especially for higher energies.

3.2 Track length

The track length gives the distance a particle travels before participating in a hadronic interaction, in units of AHCAL layers:

$$\text{real track length} = \frac{\# \text{ layers passed}}{\cos \theta} \quad (1)$$

The slope of the distribution is sensitive to high energy cross sections, especially for secondary particles created in or after the first hadronic interaction. The results of the comparison can be seen in Fig. 4.

For the mean value for all energies (Figure 4b) the physics lists all show good agreement with the testbeam data. Especially for energies higher than 20 GeV the difference between simulation and test beam data is at the order of 1%, with a slight tendency towards longer tracks in the simulation. Noise hits can influence the isolation criterion which can lead

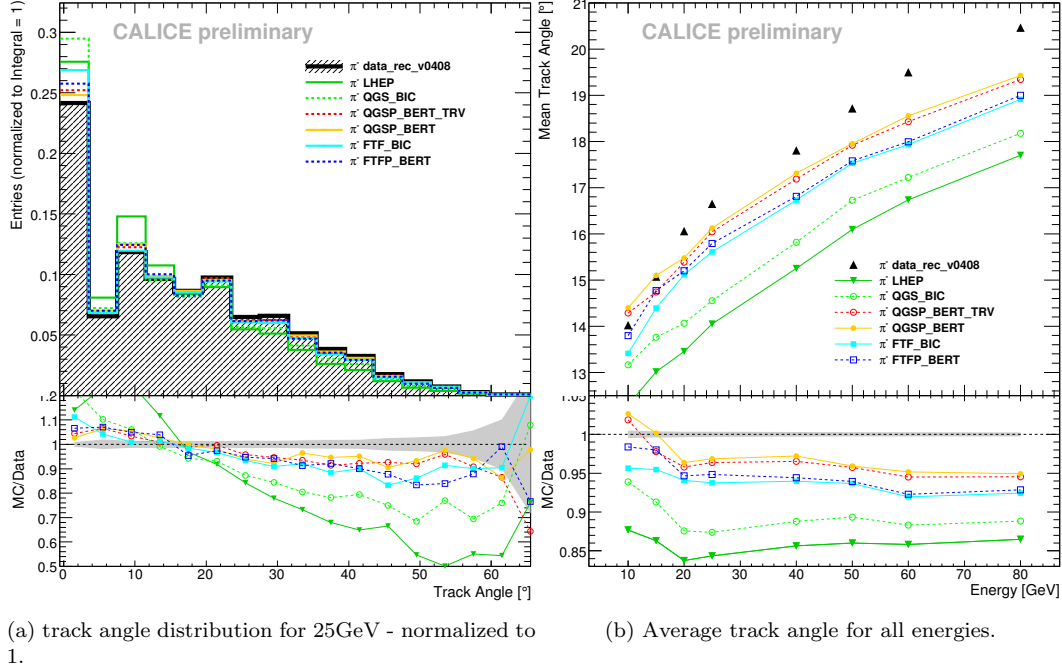


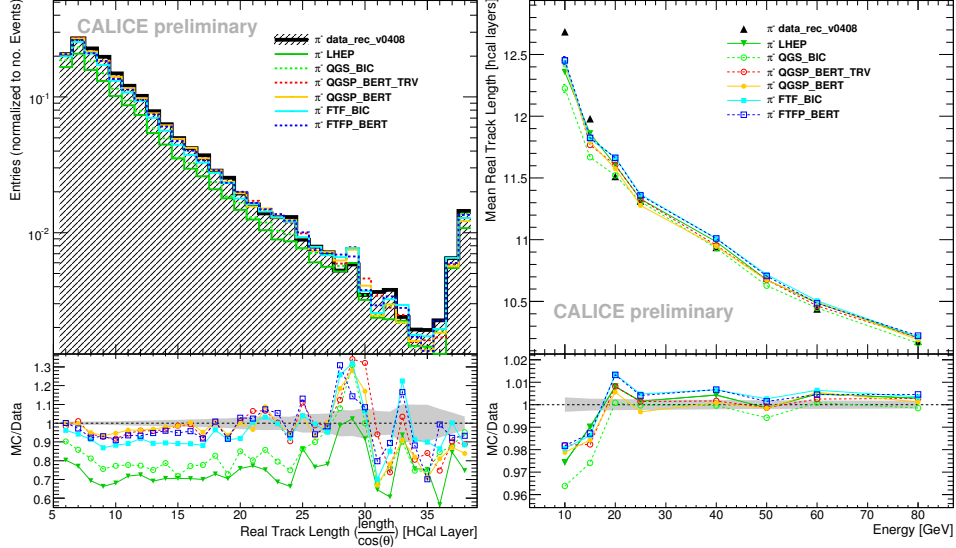
Figure 3: Data - Monte Carlo comparison: track angle for different energies. The grey area gives the size of the statistical error for LHEP.

to tracks being aborted early. If the amount of noise is not added correctly during the digitization phase of the simulated data, this will lead to a constant offset between all physics lists and the testbeam data.

The track length for the 25 GeV run in Figure 4a shows the exponential fall-off expected from the hadronic interaction of particles passing through matter. The peak at 38 layers is coming from punch through hadrons and from muons coming from $\pi^- \rightarrow \mu^- \bar{\nu}_\mu$ decays. the amount of muons and punch-through pions is well reproduced by the simulation.

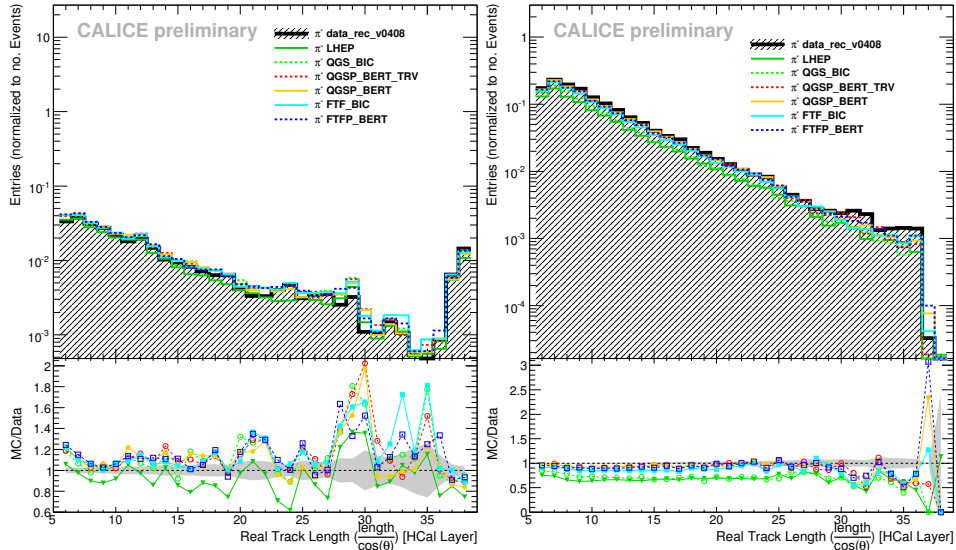
To be able to study tracks coming from the incoming beam particle (“primary” tracks) and tracks being created in hadronic interaction (“secondary” tracks) individually, the histogram from Figure 4a is split into two: For the primary tracks a histogram containing only tracks starting in layer 1 or 2 (Figure 4c) and for the secondary tracks a histogram containing tracks starting in layer 3 or later.

The histogram containing the secondary tracks can be seen in Figure 4d. Those tracks are created mainly by secondary particles coming from the shower core and hence is sensitive to the correct modeling of high energy cross sections within the physics list. Here the difference between testbeam data and simulation is below 10%, with the simulation producing less shorter tracks, but on average all physics lists produce tracks that are longer than the ones from testbeam data, which can be seen as well in Figure 4b. The fluctuations at the end are due to insufficient statistics (compare with statistical error indicated by the gray area, here



(a) track length distribution for 25GeV - normalized to number of events.

(b) Average track length.



(c) track length distribution, starting layer 1 or (d) track length distribution, starting layer ≥ 3 .

Figure 4: Data - Monte Carlo comparison: track length. 4a shows the full histogram for a 25 GeV run (normalized to the number of events). The lower plots show a decomposition of 4a, with 4c showing tracks starting in layer 1 or 2 and 4d showing all tracks starting in layer 3 or later. Both plots are normalized to number of events. Fig. 4b shows the evolution of the mean value over the entire energy range. The gray area in all ratio plots indicates the size of the statistical error taken for the LHEP physics list.

shown for the LHEP physics list). The exponential decrease is reproduced well by all physics lists, demonstrating a good description of the cross sections in the models.

The punch-through particles can be seen as well in Figure 4c showing the primary tracks. All physics lists recreate the peak around the full detector length of 38 layers. This indicates a good understanding of the simulation of the beamline, including the decay of pions to muons and the trigger. The exponential fall is interrupted for track lengths around 28-30 layers. This is due to the change in the geometry of the AHCAL from fine to coarse after the first 30 layers. Two particles resolved in the fine granularity might become unresolved and give non-isolated hits, therefore ending the track. Hence many tracks will stop in layer 30, leading to the observed length distribution for tracks starting at the front face of the AHCAL. This discontinuity in track length can be seen both for testbeam data as well as for all simulations. However, the discontinuity is more pronounced in all considered physics lists compared to testbeam data, indicating potential problems in the digitization, i.e. in the simulation of the optical crosstalk which might differ for different tile sizes and hence creates a different number of fake hits, changing the number of isolated hits.

4 Conclusion

A simple tracking algorithm has been developed that is capable of identifying tracks created by minimum ionizing particles in hadronic showers. The algorithm relies on isolated hits and works on a layer-by-layer basis. The intrinsic track properties track angle and track length are used as parameters in a comparison between testbeam data and simulations created with various physics lists. For the given data the four physics lists QGSP_BERT, QGSP_BERT_TRV, FTF_BIC and FTFP_BERT all give results that are close together and comparable to testbeam data, with a slight advantage in favor of the QGSP_BERT(_TRV) lists.

References

- [1] The CALICE Collaboration, *Construction and commissioning of the CALICE analog hadron calorimeter prototype*, JINST **5** P05004 (2010)
- [2] S. Lu, *Calibration Studies and the Investigation of Track Segments within Showers with an Imaging Hadronic Calorimeter*, arXiv:0910.3820v1 [physics.ins-det] (2009)
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